mately 60 per cent of the evaporation loss occurs during the daytime, 8 a. m. to 8 p.•m., and 40 per cent at night. Comparative day and night evaporation records are given in Table 1.

Variations in rate of evaporation.—Evaporation records were obtained from selected locations on Gatun Lake, to determine the relative rates of evaporation from the open sections of the lake and along the grass and timber covered margins. One floating pan was anchored well out in the open section of the lake. Another was located in the timber fringe bordering the south shore and a third was placed in the midst of a grassy marsh. The records were continued for six months during the rainy season, with the following results:

Evaporation from open lake, 100 per cent.
Evaporation from timber fringe, 72 per cent.
Evaporation from grassy marsh, 75 per cent.

The higher rate of evaporation from the open sections of the lake is due, principally, to the greater wind movement there, which tends to prevent the accumulation of a vapor blanket directly overlying the water surface. The rate of evaporation from the protected margin of the lake varies, depending upon the degree of protection from wind movement and direct solar radiation.

Best exposure.—Evaporation records from pans floating in lake or reservoir are considered about as accurate and representative as can be obtained under natural conditions of exposure. They are thought to be more reliable than records from pans exposed on the land surface, but care should be taken not to place the floating pan in a location too freely exposed to high winds and heavy wave action, or inaccurate records may be obtained, due to the splashing of water into or out of the pan.

Dry-season evaporation records are considered more accurate than the rainy-season records, as occasional heavy downpours in the rainy season may impair the accuracy of the records, on account of an inequality in the catch of rainfall in the evaporation pan and in the rain gage.

Monthly evaporation records at Canal Zone stations are given in Table 2, while figure 3 shows a view of a typical lake evaporation station.

TABLE 1.—*Comparative values for day and night.*[1]

Month.	1908[2]						1909			
	Ancon.		Bas Obispo.		Cristobal.		Ancon.		Cristobal.	
	Day.	Night.	Day.	Night.	Day.	Night.	Day.	Night.	Day.	Night.
	Ins.	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
January							1.755	1.593	2.754	2.114
February	5.082	1.495	3.605	2.124	4.200	3.758	2.134	1.594	2.916	2.437
March	5.566	1.431	3.919	2.371	4.402	3.155	2.693	2.238	3.660	2.785
April	4.404	1.517	3.630	1.845	3.999	2.931	2.108	1.775	3.594	2.873
May	2.001	1.218	1.715	1.460	1.706	0.864	1.317	1.134	2.268	1.600
June	2.034	1.012	1.955	1.460	1.878	1.306	0.941	0.975	1.332	1.166
July	1.900	1.117	1.670	1.580	1.584	1.238	1.078	1.002	1.252	1.193
August	2.175	1.028	1.702	1.723	1.985	1.207	1.241	1.030	1.467	1.169
September	1.924	1.125	2.178	1.457	2.096	1.231	1.425	1.059	1.706	1.021
October	2.051	1.205	2.467	1.408	2.016	1.308	1.862	0.964	1.784	1.243
November	1.362	1.052	1.555	1.175	1.572	1.128	1.395	0.937	1.129	0.821
December	1.337	1.605	2.040	1.405	2.252	1.804	1.775	1.245	1.484	1.262
Total	29.816	13.805	26.436	18.008	27.690	19.930	19.724	15.546	25.346	19.684
Per cent	68	32	60	40	58	42	56	44	56	44

1 Readings taken at 8 a. m. and 8 p. m. daily.
2 11 months, 1908.
Exposed concrete tank 12½ feet in diameter at Bas Obispo. Protected tanks 10 inches in diameter at Ancon and Cristobal.

TABLE 2.—*Monthly evaporation records.*[1]

BAS OBISPO.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	Ins.	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
1907	5.175	5.072	6.538	6.486	4.681	3.125	3.152	3.582	3.358	2.938	3.599	4.896	52.602
1908	5.617	5.729	6.290	5.475	3.175	3.415	3.250	3.425	3.635	3.875	2.730	3.445	50.061

RIO GRANDE.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1909				5.960	4.205	3.417	3.117	3.353	3.768	3.094	2.713	2.993	
1910	4.612	5.529	6.003	3.986	3.916	2.654	2.846	3.096	3.677	3.577	2.999	3.442	46.337
1911	5.940	4.912	7.462	5.139	4.015	3.646	4.989	4.564	4.096	3.924	3.055	5.344	57.086
1912	6.363	6.134	7.099	6.732	5.350	3.836	3.908	3.983	3.335	3.763	3.275	4.723	58.501
1913	5.392	5.514	6.762	6.436	4.033	3.812	3.963	3.901	3.783	3.758	2.741	4.525	54.950
1914	5.520	5.965	7.062	6.413	4.870	3.733	5.084	4.520	(2)	(2)	(2)	(2)	(2)

BRAZOS BROOK.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1909				5.366	4.597	3.806	3.042	3.760	4.169	4.168	2.152	2.379	
1910	4.622	4.688	6.151	5.025	4.304	3.516	3.014	3.189	3.804	4.177	2.718	2.746	47.934
1911	6.203	5.115	6.872	4.939	3.290	2.917	4.358	4.066	4.101	3.937	3.364	5.176	54.428
1912	6.066	5.572	7.081	7.321	5.707	3.729	4.425	4.641	4.487	3.970	3.100	4.880	60.929
1913	6.387	6.616	8.455	7.466	4.167	4.500	4.277	4.248	4.934	4.343	3.071	4.747	63.211
1914	6.331	6.456	7.769	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)

GATUN LAKE.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1911					2.799	4.560	4.407	4.583	3.609	2.681	3.376		
1912	7.208	6.048	7.649	7.394	5.335	3.263	3.883	4.316	3.799	4.123	3.351	3.560	
1913	5.435	6.889	8.602	7.333	4.606	5.083	4.664	4.570	4.934	4.841	3.560	1.291	64.811
1914	4.821	6.298	7.504	6.688	5.262	4.558	5.520	4.684	4.074	4.233	4.180	5.083	62.905
1915	6.398	5.430	6.698	5.781	5.361	5.040	4.107	4.354	4.315	4.228	3.564	4.656	59.932
1916	8.289	5.985	6.424	6.391	5.290	4.430	4.491	4.793	4.545	4.267	3.797	4.865	61.558
1917	6.194	6.229	7.248	6.514	4.903	4.110	3.903	4.008	4.851	4.750	3.617	4.899	61.224
1918	5.548	7.231	8.475	6.572	4.901	4.859	4.690	3.991	4.577	4.127	4.621	5.881	65.403

1 Records from exposed concrete tank 12½ feet in diameter at Bas Obispo.
2 Station closed.
Exposed pans 4 feet in diameter and 10 inches deep, floating in water at Rio Grande, Brazos Brook, and Gatun Lake.

EVAPORATION COMPARED WITH VAPOR PRESSURE DEFICIT AND WIND VELOCITY.

By EARL S. JOHNSTON, Associate Plant Physiologist.

[Dated: Maryland Agricultural Experiment Station, College Park, Md., Jan. 31, 1919.]

Atmospheric moisture plays an important rôle in the growth and behavior of plants and can not be overlooked in physiological and ecological studies. Atmospheric moisture conditions have frequently been studied by means of atmometers and the rate at which these instruments lose water has been taken as a measure of the evaporating power of the air.[1] The rate of evaporation from these instruments as well as the rate of transpiration from plants is greatly influenced by wind, by the temperature of the surface as dependent on radiant energy and air temperature, and by the amount of water vapor present in the atmosphere. Many attempts have been made to show a relationship between these conditions and the amount of evaporation, but most of the equations formulated are of little value in field

1 Objections have frequently been made to the expression "evaporating power of the air." Strictly speaking, the air by its presence hinders the rate of evaporation. The term here used is defined by Dr. B. E. Livingston. "Atmospheric evaporating power refers to the external surroundings of the evaporating surface (usually to the air space above it, about it, etc.) and it need not specially refer to the air itself, for if there were no air present this space would still possess an evaporating power. The evaporating power of the air over a surface is considered as proportional to the reciprocal of the tendency of all the conditions effective in the space over that surface to resist the vaporization of water therefrom." Atmometric units. Johns Hopkins Univ. Cir., March, 1917, p.160-170. (See especially p.161.) Other expressions such as "potential evaporation" and "evaporativity" have been suggested.
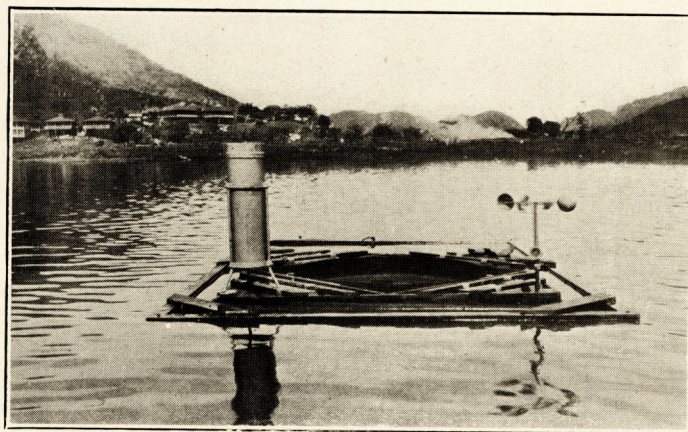
FIG. 3.—Evaporation station, Miraflores Lake.   Copper pan 4 feet in diameter and 10 inches deep floating in the lake.   The station is equipped with a rain gage, and an anemometer (seen at the edge of the pan).

experiments where only a few simple instruments are used. Atmometer readings can not be used directly when it is desired to study the moisture conditions influencing evaporation independent of air circulation. Recently Livingston [2] has suggested that for a study of such conditions the "index of atmospheric evaporating power" should be equal to the product of the index of the moisture condition and the index of circulation: $I_e = I_m \times I_c$. By moisture condition is meant "that factor in atmospheric evaporating power that is independent of the rate of air circulation." Such a condition includes the air temperature and state of saturation of the space immediately surrounding the evaporating surface. It is further assumed that actual measurements have been properly weighted before applying them as indices. A series of experiments was carried out to determine the approximate accuracy of this equation. The moisture condition measured by atmometers was compared with that calculated from the vapor pressure deficit and wind-velocity measurements.

Measurements of wind velocity and of evaporation from standardized white spherical porous-cup atmometers were made hourly on days representing various combinations of wind and moisture conditions. Vapor pressure deficits were calculated from readings of a hygrometer and thermometer for these same hour periods. These calculations were made by first determining the dew-point for each reading from data given in psychrometric tables [3] and then subtracting the vapor pressure given for the dew-point from the maximum vapor pressure of the air at the given temperature. The vapor-pressure deficit calculated for any hour period was the average of the vapor pressure deficits derived from the readings taken at the beginning and ending of the periods. Attention is called to the fact that the average vapor pressure deficit should not be calculated from the average percentage of relative humidity and the average temperature, since relative humidity and temperature do not always vary in a similar manner. The atmometer and anemometer were freely exposed to the air while the hygrometer and thermometer were exposed within an instrument shelter similar to those employed by the United States Weather Bureau. Data from these instruments and the calculated values are presented in Table I.

Each experiment in Table I is designated by a date of the year 1918. The beginning and ending of each hour period is given as clock time in the first column. In the succeeding columns are given air temperature in degrees Fahrenheit, percentage of relative humidity, vapor pressure deficit in inches of mercury, wind velocity in miles per hour, product of vapor pressure deficit and wind velocity, evaporation in cubic centimeters of water lost from an atmometer corrected to the standard sphere and radiation expressed as the difference in the amounts of water lost from the black and white components of a radio-atmometer.[4] The character of the sky during each period is given in the last column.

[2] Livingston, B. E., The vapor pressure deficit as an index of the moisture condition of the air. Johns Hopkins Univ. Cir., March, 1917. p. 170-175.

[3] Marvin, C. F., Psychrometric tables for obtaining the vapor pressure, relative humidity, and temperature of the dew-point. U. S. Dept. Agric. Weather Bureau No. 235. 1910.

[4] Livingston, B. E., Atmometry and the porous cup atmometer. IV. The radio atmometer. Plant World 18:143-149. 1915.

TABLE I.—Calculated and observed data.

Date and period.	Air temperature.	Humidity.	Vapor pressure deficit.	Wind velocity.	Product of vapor pressure deficit and wind velocity.	Evaporation.	Radiation (B-W).	Character of sky.
	°F.	Per ct.	In. Hg.	Mi. hr.		Cc.	Cc.	
Sept. 12:								
11-12	74	64	0.308	9.7	2.99	2.6	0.0	Partly cloudy.
12-1	76	54	0.423	8.3	3.51	3.0	1.8	Partly cloudy.
1-2	77	52	0.468	7.2	3.37	3.0	1.1	Partly cloudy.
2-3	78	51	0.484	6.2	3.00	3.1	0.5	Partly cloudy.
3-4	77	53	0.451	6.9	3.11	2.5	0.9	Cloudy.
4-5	76	58	0.388	8.3	3.22	2.2	0.9	Cloudy.
Aug. 16:								
7-8	66	76	0.162	1.6	0.26	0.5	0.7	Clear.
8-9	73	66	0.288	3.6	1.04	0.7	2.0	Clear.
9-10	78	48	0.491	3.5	1.72	2.9	1.3	Clear.
10-11	80	37	0.643	5.5	3.54	3.7	1.4	Clear.
11-12	82	34	0.712	5.9	4.20	4.1	1.7	Clear.
12-1	83	33	0.740	5.1	3.77	4.7	1.8	Slightly cloudy.
1-2	84	32	0.765	5.0	3.82	4.3	1.8	Slightly cloudy.
2-3	84	32	0.765	6.1	4.67	4.9	1.3	Partly cloudy.
3-4	84	32	0.765	4.7	3.60	4.1	1.8	Partly cloudy.
4-5	84	33	0.776	4.1	3.18	3.5	2.2	Partly cloudy.
5-6	84	35	0.736	4.5	3.31	4.0	0.7	Slightly cloudy.
Aug. 20:								
10-11	72	51	0.397	2.6	1.03	2.3	1.5	Slightly hazy.
11-12	74	46	0.451	5.4	2.44	3.2	1.9	Slightly hazy.
12-1	75	42	0.514	7.1	3.65	3.8	1.8	Slightly hazy.
1-2	77	38	0.571	6.1	3.48	4.0	1.6	Slightly hazy.
2-3	78	35	0.625	6.2	3.87	4.1	2.1	Slightly hazy.
3-4	78	34	0.632	6.6	4.17	4.6	1.1	Slightly hazy.
4-5	77	36	0.598	5.0	2.99	3.5	1.5	Slightly hazy.
Sept. 21:								
10-11	56	52	0.217	13.4	2.91	2.4	0.8	Partly cloudy.
11-12	57	49	0.237	13.9	3.29	2.7	0.5	Cloudy.
12-1	58	47	0.254	13.8	3.51	3.1	1.1	Cloudy.
1-2	59	47	0.263	14.3	3.76	3.7	0.7	Cloudy.
2-3	60	46	0.271	10.2	2.76	3.0	0.5	Partly cloudy.
3-4	60	44	0.293	8.7	2.55	2.0	1.1	Partly cloudy.
4-5	60	46	0.288	9.9	2.85	2.9	0.1	Partly cloudy.
Aug. 23:								
9-10	77	65	0.333	5.1	1.70	2.2	1.0	Clear.
10-11	81	58	0.453	5.4	2.45	2.5	1.5	Clear.
11-12	84	53	0.559	6.8	3.80	3.0	1.6	Clear.
12-1	86	48	0.646	9.4	6.07	4.8	2.0	Clear.
1-2	87	45	0.707	7.3	5.16	4.5	1.6	Clear.
2-3	89	44	0.780	7.8	6.08	4.7	1.5	Clear.
3-4	89	43	0.800	7.8	6.24	4.6	1.5	Slightly cloudy.
4-5	88	42	0.777	7.6	5.90	4.6	1.5	Slightly cloudy.
Sept. 28:								
9-10	53	83	0.069	1.5	0.10	0.5	0.4	Slightly hazy.
10-11	58	71	0.145	2.3	0.33	0.6	0.6	Slightly foggy.
11-12	62	58	0.240	4.6	1.10	2.0	0.2	Slightly hazy.
12-1	65	49	0.314	9.2	2.89	2.2	1.5	Slightly hazy.
1-2	67	44	0.374	10.2	3.82	3.4	1.2	Cloudy.
2-3	68	43	0.409	9.3	3.80	3.2	0.7	Cloudy.
3-4	68	42	0.414	9.9	4.10	3.1	0.8	Slightly cloudy.
4-5	68	42	0.396	8.7	3.45	3.5	0.7	Slightly cloudy.

These data, plotted as ordinates, are represented in figures 1 and 2. Each value is plotted at the end of its respective period along the abscissas. In figure 1 the vapor pressure deficit values are represented as dotted lines, wind velocity as dash lines, and evaporation as *light* full lines. The *heavy* full lines represent the product of vapor pressure deficit and wind velocity values. In figure 2 the graphs of evaporation are repeated in order to facilitate comparison with air temperature (dotted lines), relative humidity (dash lines), and radiation (dash-dot lines).

Inspection of figure 1 shows a very good agreement between the calculated evaporation (product of vapor pressure deficit and wind velocity) and that obtained from the atmometers. The effect of sudden changes in wind velocity are registered in several cases. Air temperatures were employed in calculating the vapor pressure deficits. The temperature at the evaporating surface of the atmometer is usually lower than that of the air, thus reducing the actual vapor pressure of the water particles escaping from the atmometer. This vapor is also lowered because the

water evaporates from an imbibing substance and not from a free water surface. From a consideration of these facts it is to be expected that in many cases the actual evaporation values will be somewhat lower than the calculated ones. In bright sunlight, however, when absorbed

The average evaporation found in this series of experiments is 3.16 cc. per hour while that of the calculated is 3.24 cc. The approximate accuracy of this simple relation makes it possible to roughly calculate wind velocity from atmometer, hygrometer, and temperature readings, or, to
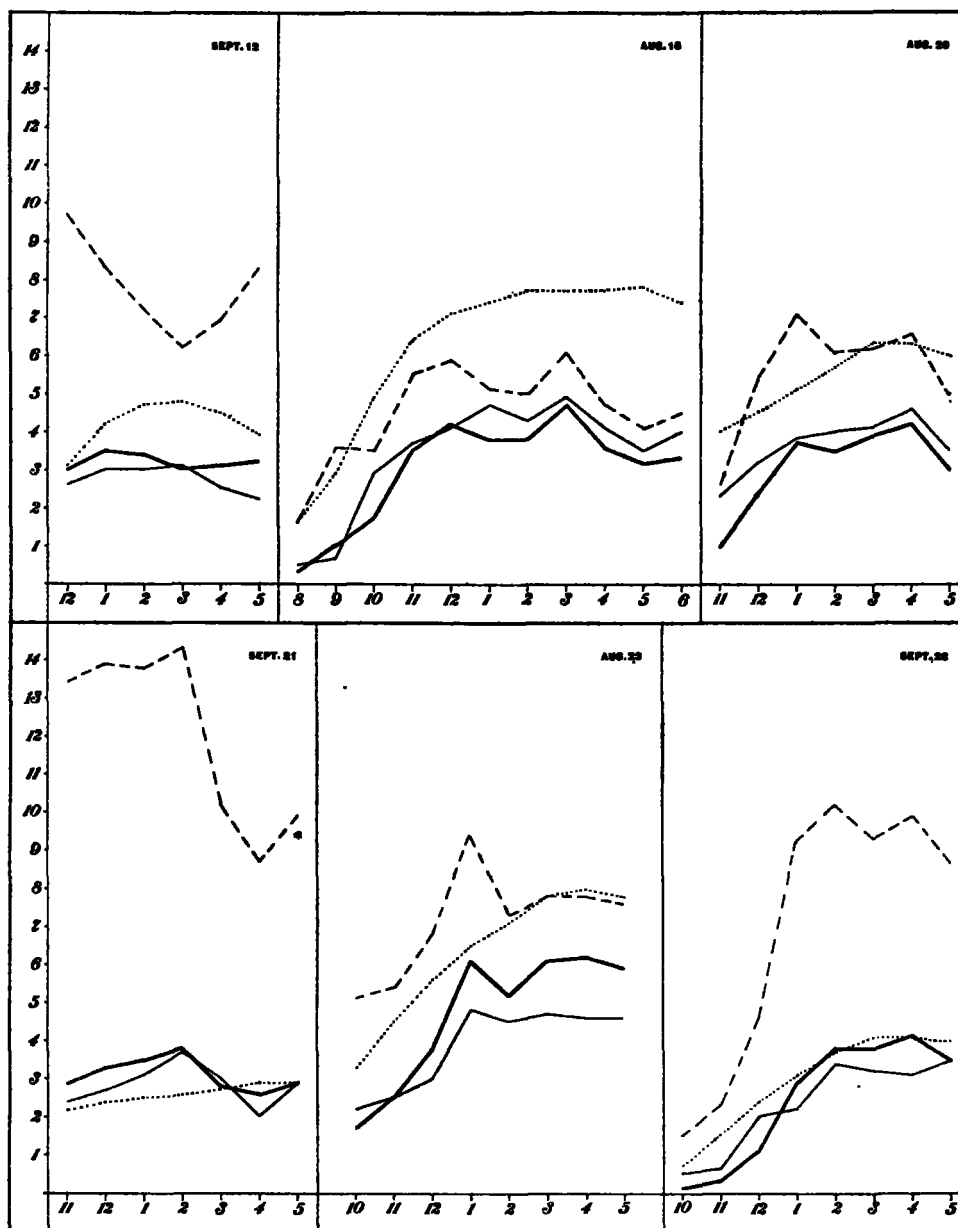
Fig. 1.—Graphs of values representing evaporation from porous-cup atmometers (light full lines), calculated evaporation (heavy full lines), vapor pressure deficit (dotted lines), and wind velocity (dash lines).

radiant energy increases the temperature at the evaporating surface, thus increasing the vapor pressure, the actual evaporation values will become more nearly equal to and perhaps exceed those of the calculated. These facts, in part, account for some of the variations in agreement between the graphs of evaporation from this type of atmometer and the graphs of the calculated evaporation.

calculate the moisture condition of the atmosphere independent of wind velocity when atmometric and anemometric measurements are available. It is to be remembered, however, that these relations have been tested for a limited range of conditions only and whether such relations will hold true for more extreme conditions has not yet been worked out. In figure 2 the graphs of relative

humidity and of evaporation deserve special note. The lack of relationship between the graphs of these two kinds of data is clearly seen and the employment of relative humidity independent of temperature is obviously of little importance in evaporation and transpiration studies.

No attempt will be made at this time to show just why or how this approximate relation holds true or to discuss any evaporation formulas. The present purpose

INCREASE OF PRECIPITATION WITH ALTITUDE.[1]

By Alfred J. Henry, Meteorologist.

Thirty-odd years ago, when the irrigation of arid regions in southwestern United States was first seriously considered, much embarrassment was caused by lack of definite knowledge as to the increase of precipitation with increase of altitude.
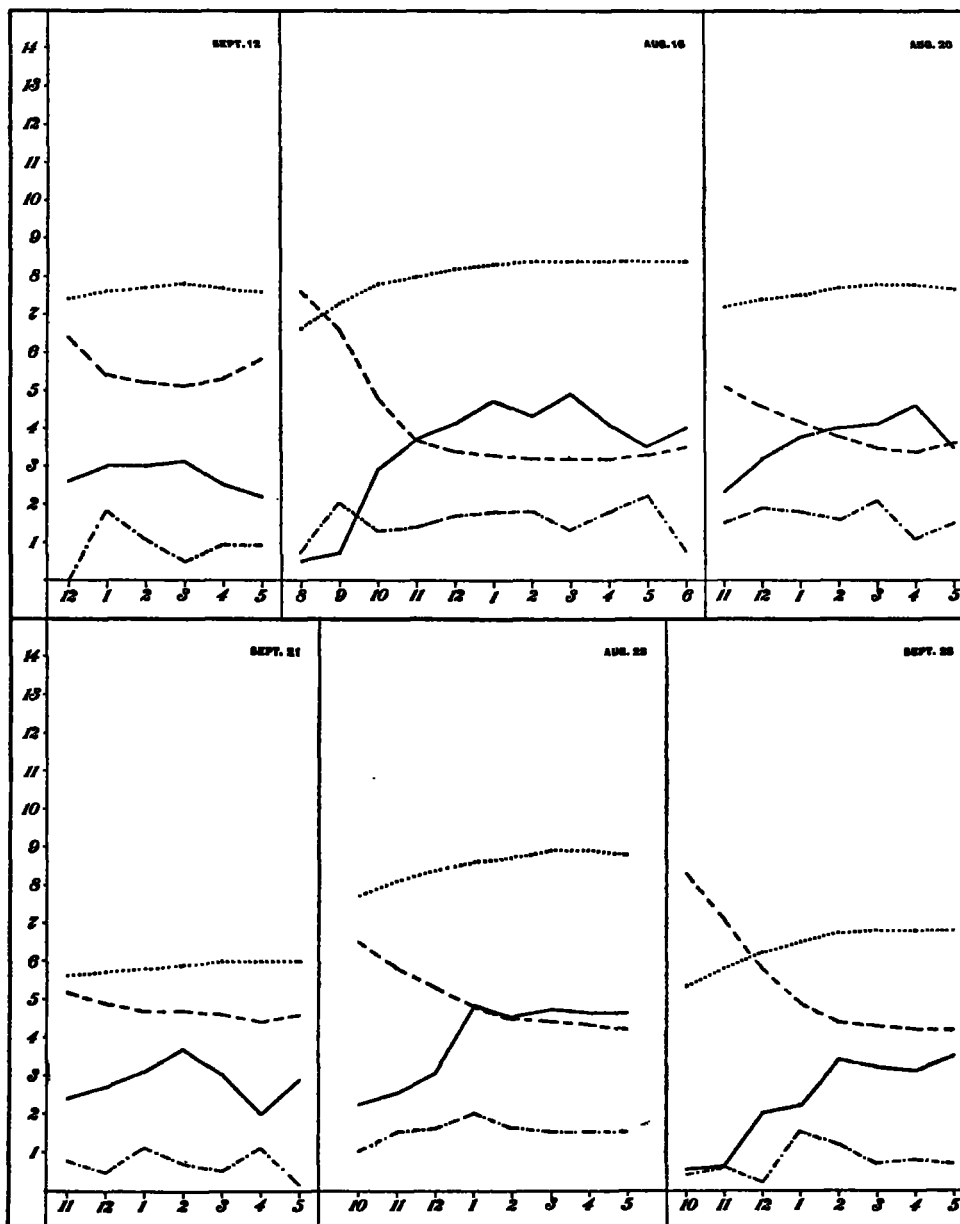

FIG. 2.—Graphs of values representing evaporation from porous-cup atmometers (full lines), air temperature (dotted lines), relative humidity (dash lines), and "radiation" (dash-dot lines).

is to present the results of a number of experiments that were carried out with the object of testing this particular relation suggested by Livingston. This paper is mainly intended for the ecologist. A suggestion is given as to how relative humidity and temperature data, together with those of wind velocity, may be used apparently to as good advantage as evaporation data. This should help make a large amount of the valuable data collected by the Weather Bureau more directly useful to his particular needs.

For the sake of brevity, the relation between the increase in precipitation in connection with increasing altitude above sea level will be referred to hereafter in this paper as the "precipitation-altitude relation."

In the absence of gage records, various methods have been used to interpolate the rainfall of higher altitudes, the most common one being based on considerations of vegetal cover and topography.

[1] Read before the Association of American Geographers, Baltimore, Md., Dec. 27, 1918.